Loss of shrimp by turtle excluder devices (TEDs) in coastal waters of the United States, North Carolina to Texas: March 1988–August 1990

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Abstract.–Observers from the National Marine Fisheries Service collected information on catch rates of shrimp aboard commercial shrimp vessels during March 1988–August 1990. Comparisons were made between nets equipped with Turtle Excluder Devices (TEDs) and standard shrimp nets. Three types of TEDs were tested: Georgia TEDs with and without accelerator funnels, and Super Shooter TEDs with funnels.

Fishing areas, time of day, and duration of tows were controlled by the captain of each vessel to simulate commercial conditions. A statistically-significant ($P<0.05$) mean loss in shrimp catch-per-unit-effort (CPUE) of 0.24 lb/h (3.6%) and 0.93 lb/h (13.6%) was exhibited by nets equipped with Georgia TEDs (with and without funnels, respectively) compared with standard nets. There was no significant difference in shrimp CPUE between standard nets and nets equipped with Super Shooter TEDs with a funnel.

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The National Marine Fisheries Service (NMFS) promulgated regulations which required the use of Turtle Excluder Devices (TEDs) on offshore shrimp vessels beginning in June 1987 (Federal Register 1987), depending upon vessel size, geographic location, and season. In offshore waters, all shrimp trawlers 25 ft and longer must use approved TEDs, and shrimp trawlers smaller than 25 ft are required to restrict tow times to 90 min or less. All shrimp trawlers not pulling TEDs must restrict tow times to 90 min or less in inshore waters. Shrimp trawlers using TEDs are exempt from tow time restrictions in both inshore and offshore waters. TED use in the Gulf of Mexico is required during 1 March–30 November inshore and offshore. In the Atlantic, TEDs are required both inshore and offshore during 1 May–31 August, except for waters off Cape Canaveral and southwest Florida where TEDs are required year-round.

The shrimp fishery in the Gulf of Mexico and southeastern United States is valued at approximately $470 million. Fishing occurs year-round in the Gulf of Mexico, with peak landings in summer for brown shrimp, in fall for white shrimp, and in winter and spring for pink shrimp (Klima et al. 1986, Magnuson et al. 1990). Similarly in the Atlantic, peak landings occur in summer for brown shrimp and in fall for white shrimp (Magnuson et al. 1990).

According to shrimp fishermen, the use of TEDs reduces shrimp catches to the point that their livelihoods are threatened. In 1988, both the Office of Management and Budget (OMB) and the House Appropriations Committee mandated certain studies testing and evaluating the impacts of TED use. The OMB required a study on the efficiency of TEDs in excluding turtles, and the House Appropriations Committee required a study of the full economic impact of TEDs.

NMFS, in cooperation with the shrimp industry, initiated a TED Evaluation Program on 5 March 1988. The objective of this program was to compare shrimp catch rates of TED-equipped trawls with shrimp catch rates of standard trawls in shrimp fishing grounds from North Carolina to Texas. The assumption was that shrimp CPUEs were equal both for vessels from this study and from the commercial fleet fishing during the same seasons and in the same Statistical Areas (Fig. 1). This paper reports on the results of the program and on estimates of total shrimp loss to the fishery through the use of TEDs.

Materials and methods

Recruitment of vessels

Participation in the study by shrimpers was voluntary. Vessels and crews were neither leased nor chartered by NMFS. A payment of \$100/d was sometimes provided by the Gulf and South Atlantic Fisheries Development Foundation, generally when TEDs were not required by law. This was an incentive for vessel owners to allow NMFS personnel to collect data while on board their vessels.

Vessels were recruited with the assistance of NMFS port agents, NOAA Sea Grant Marine Advisory agents, regional shrimp associations, and industry contacts. All participating vessels received appropriate federal authorization to use TEDs in only half the trawls when a NMFS observer was on board. Twenty-six quad-rigged vessels (two trawls towed/side) and one twin-rigged vessel (one trawl towed/side) were used in the study.

Areas

Beginning in March 1988, observers were placed on shrimp vessels in each of the four major Gulf of Mexico offshore fishing areas (Louisiana, Texas, south Florida, and Alabama-Mississippi) and in the Atlantic off Florida, Georgia, and North Carolina. Higher levels of observer effort were allocated for areas which historically had higher shrimp production. Of 600 planned observer days, 240 were scheduled for Louisiana, 200 for Texas, 50 each for east and west Florida, and 60 for Mississippi-Alabama. One-hundred observer days were also scheduled for Georgia and North Carolina waters. Observer days were targeted for peak regional shrimping seasons in each area, although this schedule was not always implemented due to constraints of voluntary participation by the shrimp industry.

The U.S. coasts of the Gulf of Mexico and Atlantic Ocean are divided into Statistical Areas (Fig. 1) by NMFS for analytical purposes. Areal groupings for analyses in this study were Statistical Areas 1–8 (West Florida), 9–12 (Florida Panhandle, Alabama, and Mississippi), 13–17 (Louisiana), 18–21 (Texas), 28 (Cape Canaveral), 30–31 (East Florida and Georgia), and 34–35 (North Carolina).

The study depended on shrimpers volunteering to allow NMFS personnel to collect data onboard their vessels. Due to limited response by shrimpers, data came from virtually any vessel whose owner or captain would allow NMFS aboard. Since one of the principal objectives of this study was to evaluate the effect of the use of TEDs on commercial shrimping, the shrimpers decided where and when to fish and which certified TED to use. Our only stipulations were that the shrimper had to use federally approved TEDs, allow gear specialists to properly adjust the TEDs, and keep catches from all nets of

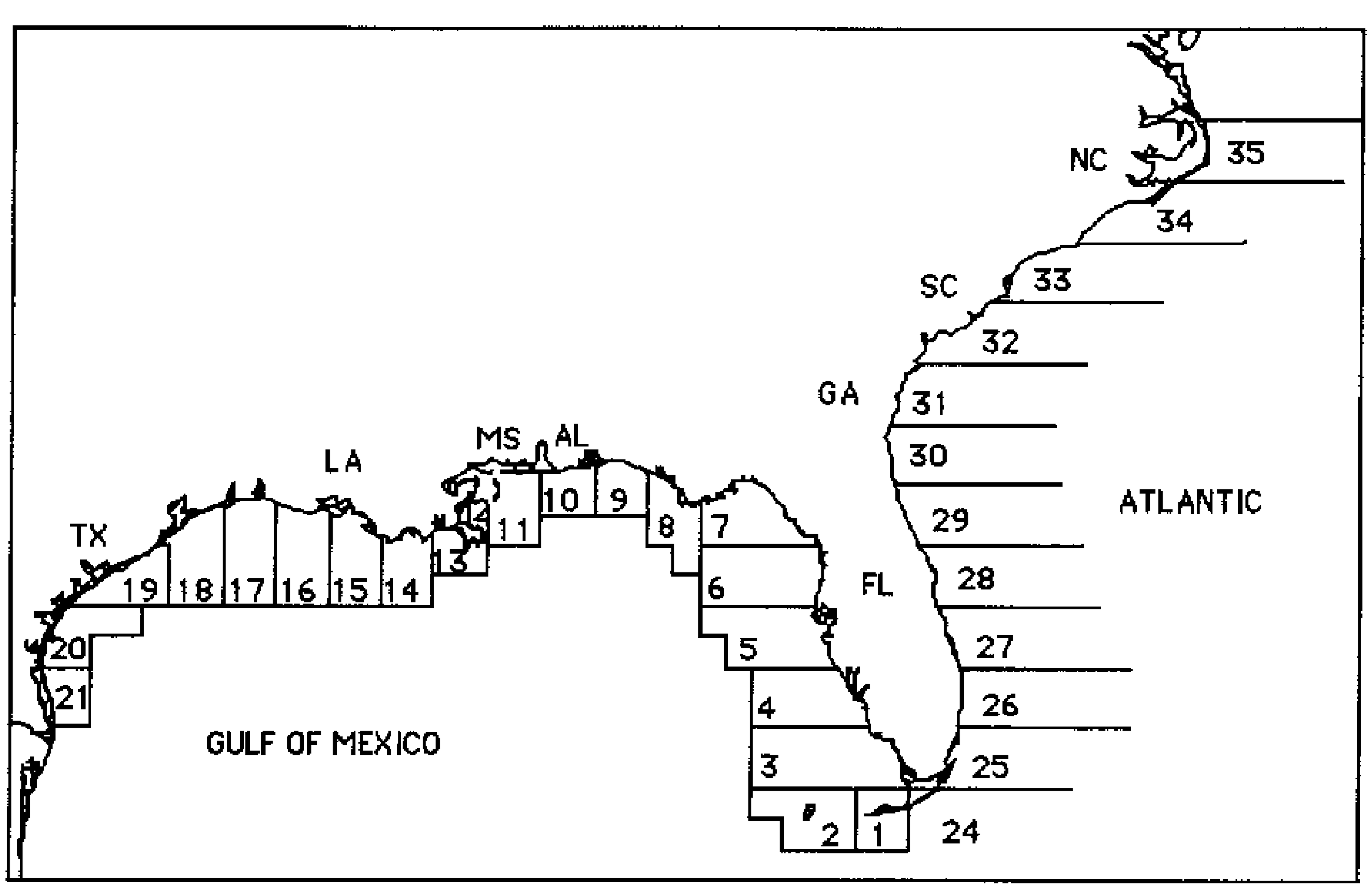

Figure 1
NMFS Statistical Areas in the Gulf of Mexico and Atlantic.

a tow separate to facilitate data collection on deck. The conditions under which the data were collected were assumed to be representative of commercial fishing conditions.

Gear tuning and control tows

The fishing efficiency of all nets used in this study was standardized by NMFS or Sea Grant gear specialists during the initial trip of a participating vessel. Prior to installation of TEDs, control tows were made using standard nets. Lazy line, tickler chain, and float adjustments were made to each net until approximately equal amounts of shrimp were caught by every net.

Vessel captains were instructed by gear specialists on the proper installation of TEDs. Once TEDs were installed, the gear specialist modified the rigging for the proper operation of the TED. This procedure usually required 2–3 d. The captain then was responsible for later gear tuning. Differences in the tuning ability of captains may contribute to variations in the catch data. All Super Shooter TEDs were constructed with accelerator funnels (Fig. 2), i.e., mesh in the shape of a funnel sewn into the net directly in front of the TED. Funnels accelerate water flow through the TED and into the cod end of the net. Georgia TEDs were tested with and without funnels.

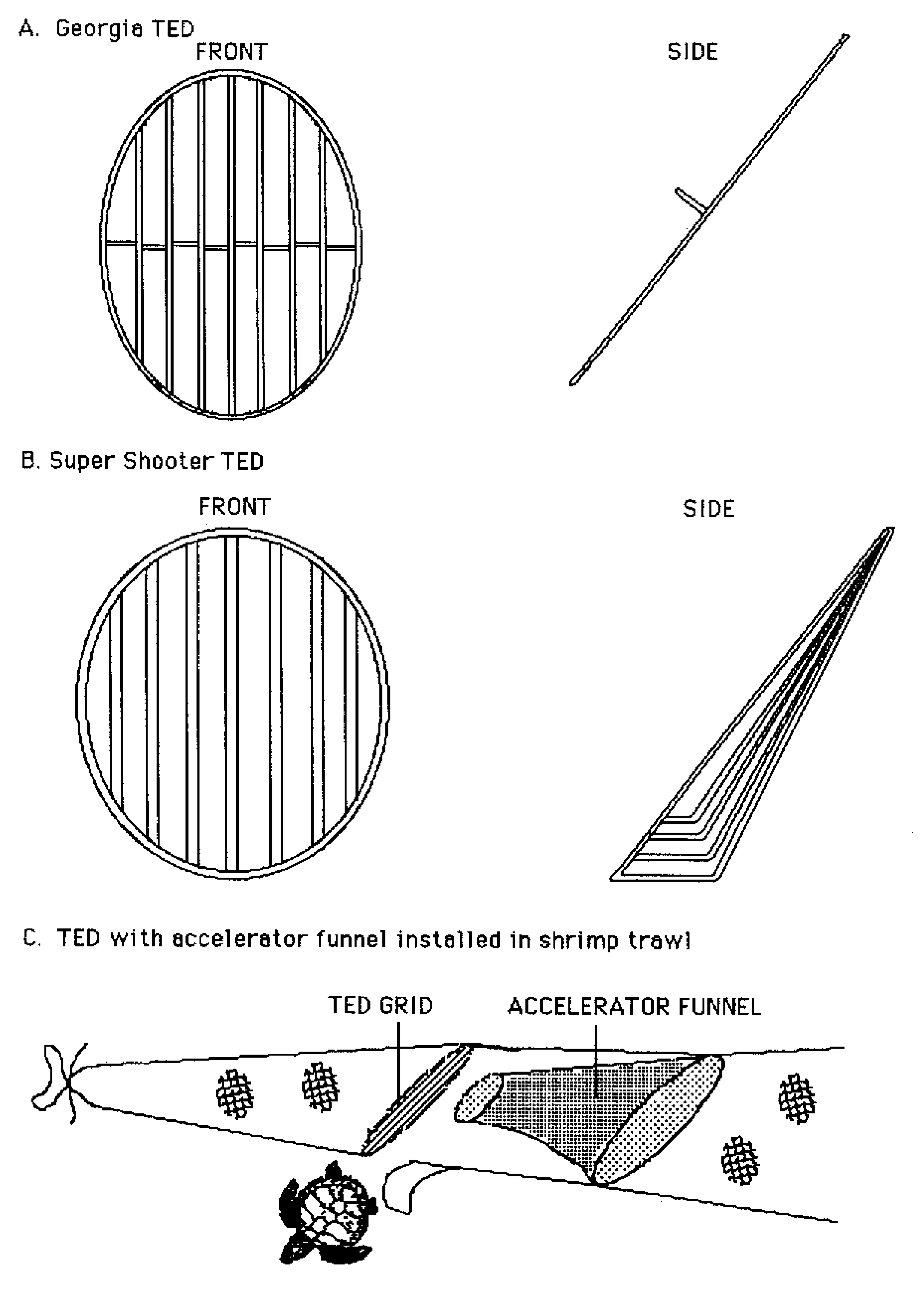

Figure 2
Schematics of Georgia and Super Shooter TEDs and accelerator funnel.

Data collection

Every phase of the operation was explained to vessel captains by NMFS personnel to insure that all data could be collected. Aside from sampling the catch and working up the data, observers did not interfere with normal fishing activity. The primary requirement of the study was that catches from each net be kept separate from all others so the shrimp from each trawl could be weighed and recorded. If necessary, the back deck of the vessel was partitioned with wooden beams to prevent catches from mixing. Captains of the vessels were requested to examine the data collected by the NMFS observer and to sign the data sheets to verify their accuracy.

Shrimp catch on observer vessel A random sample weighing 50–70 lb was shoveled from the contents of each trawl into standard-sized plastic shrimp baskets. Thus, a quad-rigged vessel produced four samples per tow and a twin-rigged vessel two samples per tow. Shrimp were separated from each sample and total weight (to the nearest lb) of brown, pink, and white shrimp (*Penaeus* sp.) combined was recorded for every net of each tow. No analysis by species was possible or proposed by this study. If the shrimper discarded small shrimp, observers were instructed to include only the size-range of shrimp retained by the shrimpers for their weights. Catch was recorded as heads-on or heads-off. Heads-off weight = (0.63 heads-on weight).

For each tow, shrimp CPUE (heads-off lb/h/100 ft of headrope towed) from all TED-equipped nets were averaged and compared against the average shrimp CPUE of all standard nets, to provide one TED-standard data pair per tow. Unless otherwise stated, shrimp CPUE will refer to heads-off lb/h/100 ft of headrope. The average CPUEs of two TED-equipped and two standard nets were paired for each tow for 26 quad-rigged vessels and 1 twin-rigged vessel. However, if one net was excluded from the analysis due to unacceptable operation (refer to Gear Performance), then the CPUE value from the remaining net was paired with the average of CPUEs from the other two nets. If both nets of a given gear type malfunctioned, all data from that tow were deleted from the analysis. Standard and experimental nets were compared on twin-rigged vessels and these data pooled with those from quad-rigged vessels.

Commercial shrimp catch Effort data for a given temporal and spatial area were calculated by taking the average trip CPUEs (heads-off lbs/24 h day/4 nets), obtained by interviewing vessel captains, and extrapolating to total effort by using the total-pounds value from dealers' records. Fishing-effort data on the shrimp fleet have been collected in this manner since 1960. These data were compared with CPUEs (heads-off lbs/24 h day/4 nets) from our observer trips. The assumption that shrimp CPUEs were equal, both for vessels from this study and from the commercial fleet fishing during the same seasons and in the same Statistical Areas, was tested using a paired *t*-test with a probability level of 0.05.

Gear performance Each net was characterized by an operation code based on its performance in the water. Codes were used to describe successful tows or problems encountered, such as tangling of trawl doors, gear fouling, twisted cables, bag choking, etc. Two codes were occasionally required to describe trawl performance.

Data collected from the problematic tows not related to TEDs, e.g., cod end coming untied, gear not fishing properly, torn nets, and broken cables, were not included in the analyses. Chi-square ($P<0.05$) analysis was used to determine if the problematic tows were independent of net type (e.g., TED-equipped nets or standard nets) by area (Gulf of Mexico or Atlantic).

Statistical analyses

Paired t-tests Paired *t*-tests were performed to test the hypothesis of equal CPUE of shrimp by standard and TED-equipped trawls. Data were paired by tow. Confidence intervals (95%) on CPUE were also calculated.

Biological models Deterministic population models were produced for brown shrimp *Penaeus aztecus*, white shrimp *P. setiferus*, and pink shrimp *P. duorarum* by linking a Ricker-type yield-per-recruit model to recruitment estimates that were independent of parent stock (Ricker 1975, Nichols 1984, Nance & Nichols 1988). Recruitment level was set at the geometric mean for the complete data set (1960–88). Estimates for 1986–89 fishing mortality rates (F) were derived from virtual population analysis, and the average was used as the baseline for current conditions. Yield estimates were made for all three species for a range of "F-multiplier" values of 0–2 by 0.02 increments. Tables of these yield estimates were used to determine effects of TED-equipped nets on the shrimp yield in the Gulf of Mexico. This was possible because yield estimates (Y_t) are a direct result of fishing mortality rates (Royce 1972). The yield model was

$$Y_t = F_t \, N_t \, W_t \, dt \,,$$

where N_t is the number of animals (R) in a cohort subject to fishing (F) and natural (M) mortality at a given time (t), using the formula

$N_t = Re^{-(F+M)(t-t_0)}$,
F_t = fishing mortality at a given time,
W_t = average weight of an individual at time t, estimated from growth equations.

Fishing mortality rate (F) is the product of two separate variables, a catchability coefficient (q) and directed nominal fishing effort (f):

$$F = qf.$$

TED-equipped nets influence fishing mortality (F) by affecting shrimp catchability (q), and not fishing effort (f). Any percentage change in shrimp catchability caused by TED-equipped nets was assumed to be directly reflected in an equal percentage change in fishing mortality. This is based on an assumption of direct proportionality between change in CPUE and change in q. Thus, any change in CPUE as a result of TED use is translated into a proportional change in q.

Results

Descriptive data summary

Paired data In the Gulf of Mexico, 589 data pairs were collected using Georgia TEDs equipped with accelerator funnels, 59 pairs from Georgia TEDs without funnels, and 50 pairs from Super Shooter TEDs with

Table 1
Frequency of paired tows for standard nets and nets equipped with Super Shooter TEDs with funnel (SF), Georgia TEDs with funnel (GF), and Georgia TEDs without funnels (G) by season and area.

	Winter			Spring			Summer			Fall		
Areas*	SF	GF	G	SF	GF	G	SF	GF	G	SF	GF	G
WFL (1–8)	2	17	–	15	79	10	–	–	–	–	–	–
MAFP (9–12)	–	28	–	11	3	–	–	20	–	–	39	–
LA (13–17)	–	60	–	22	55	–	–	25	21	–	104	–
TX (18–21)	–	3	5	–	1	–	–	88	–	–	67	23
CCFL (28)	–	–	60	–	–	–	–	–	–	–	–	–
EFLG (30–31)	–	30	–	–	–	–	–	21	163	–	35	–
NC (34–35)	–	–	–	–	–	–	186	–	–	–	–	–
Totals	2	138	65	48	138	10	186	154	184	0	245	23

* Areas 1–8 (West Florida), 9–12 (Florida Panhandle, Alabama, Mississippi), 13–17 (Louisiana), 18–21 (Texas), 28 (Cape Canaveral), 30–31 (East Florida and Georgia), and 34–35 (North Carolina).

funnels. There were 86 and 223 data pairs in the Atlantic for Georgia TEDs with and without accelerator funnels, respectively, and 186 pairs for Super Shooter TEDs with funnels. Frequencies of data collection by geographic area and season (winter: December–February, spring: March–May, summer: June–August, fall: September–November) are presented in Table 1.

Performance of TED-equipped and standard nets Data were collected from 5937 nets during the 2.5 yr study. Frequency of net problems was tabulated by TED type. The most frequent problems included clogging of the net, twisting of trawl doors and cables, and torn webbing. In the Gulf of Mexico, no problems occurred during 86%, 87%, 75%, and 87% of the tows for nets equipped with Georgia TEDs with and without funnels, Super Shooter TEDs and standard nets, respectively (Table 2). In the Atlantic, the values were 96%, 90%, 89%, and 95% for the respective gear types (Table 2). A variety of problems, including but not limited to those with trawl doors, cables, bogging-down of nets, etc., were shown to be net-type independent (e.g., TED-equipped nets or standard nets) in the Gulf of Mexico and net-type dependent in the Atlantic (chi-square, $P<0.05$).

Table 2
Comparison of net types and gear-related problems in the Gulf of Mexico and Atlantic for Georgia TEDs with (GF) and without (G) funnels, Super Shooter TED with funnel (SF), and standard shrimp nets (STD). Sample includes all nets used from all vessels during the study. Values represent the percent of nets in each category; totals may not equal 100% due to rounding.

	STD	G	GF	SF
	(n=2356)	(n=199)	(n=1243)	(n=185)
Gulf of Mexico				
None	87	87	86	75
Clogging, choking	4	4	6	7
Doors, cables	4	5	5	2
Torn webbing	3	4	2	4
Other	2	0	1	12
Atlantic				
None	95	90	96	89
Clogging, choking	3	0	3	6
Doors, cables	2	10	0	4
Torn webbing	1	0	0	1

Testing of paired tows

Reduction of shrimp CPUE associated with use of TEDs Mixtures of brown and white shrimp were captured in all areas of the Gulf and Atlantic, except for the west coast of Florida where pink shrimp were prevalent. Shrimp species were not separated for analyses.

There was no significant difference ($P<0.05$) in net sizes among vessels in this study, so this parameter was excluded from any further analyses. Summaries of shrimp CPUEs by TED type, season, and area are presented in Tables 3–5. Mean shrimp CPUEs for Geor-

Table 3
Comparisons (paired t-test) between shrimp CPUE (heads-off lbs/h/100 ft headrope) of standard (STD) and Super Shooter-equipped nets with accelerator funnel. N = number of tows.

		Mean CPUE			Gain (loss) by use of TED	
	N	STD net	TED net	P	CPUE	Percent
Overall	236	11.41	11.25	0.58	(–0.16)	(–1)
Seasons*						
Winter	2	16.74	15.79	—	(–0.95)	(–6)
Spring	48	8.70	8.57	0.69	(–0.12)	(–1)
Summer	186	12.05	11.89	0.66	(–0.16)	(–1)
Areas**						
1–8	17	13.92	12.70	0.01	(–1.22)	(–9)
9–12	11	2.44	2.63	0.06	0.19	+8
13–17	22	8.52	9.00	0.12	0.48	+6
33–35	86	12.05	11.89	0.70	(–0.16)	(–1)

* Winter (December–February), Spring (March–May), Summer (June–August), Fall (September–November).
** Areas 1–8 (West Florida), 9–12 (Florida Panhandle, Alabama, Mississippi), 13–17 (Louisiana), 18–21 (Texas), 28 (Cape Canaveral), 30–31 (East Florida and Georgia), and 34–35 (North Carolina).

Table 4
Comparisons (paired t-test) between shrimp CPUE (heads-off lbs/h/100 ft headrope) of standard (STD) and Georgia TED-equipped nets **with** accelerator funnel. N = number of tows.

		Mean CPUE			Gain (loss) by use of TED	
	N	STD net	TED net	P	CPUE	Percent
Overall	674	6.66	6.42	0.02	(–0.24)	(–4)
Seasons*						
Winter	138	4.12	4.46	<0.01	0.34	+8
Spring	138	4.51	3.95	<0.01	(–0.56)	(–12)
Summer	154	9.23	8.56	<0.01	(–0.67)	(–7)
Fall	244	7.70	7.58	0.82	(–0.12)	(–2)
Areas**						
1–8	96	5.22	4.69	0.01	(–0.53)	(–10)
9–12	90	7.53	7.18	0.21	(–0.35)	(–5)
13–17	244	5.69	5.40	<0.01	(–0.29)	(–5)
18–21	158	7.42	7.40	0.99	(–0.02)	(–0)
28	86	8.77	8.67	0.84	(–0.10)	(–1)

* Winter (December–February), Spring (March–May), Summer (June–August), Fall (September–November).
** Areas 1–8 (West Florida), 9–12 (Florida Panhandle, Alabama, Mississippi), 13–17 (Louisiana), 18–21 (Texas), 28 (Cape Canaveral), 30–31 (East Florida and Georgia), and 34–35 (North Carolina).

Table 5
Comparisons (paired t-test) between shrimp CPUE (heads-off lbs/h/100 ft headrope) of standard (STD) and Georgia TED-equipped nets **without** accelerator funnel. N = number of tows.

		Mean CPUE			Gain (loss) by use of TED	
	N	STD net	TED net	P	CPUE	Percent
Overall	284	6.77	5.84	<0.01	(–0.93)	(–14)
Seasons*						
Winter	65	4.77	4.59	0.52	(–0.18)	(–4)
Spring	10	6.06	3.86	0.25	(–2.20)	(–36)
Summer	186	7.66	6.53	<0.01	(–1.13)	(–15)
Fall	23	5.48	4.78	<0.01	(–0.70)	(–13)
Areas**						
1–8	10	6.06	3.86	0.25	(–2.20)	(–36)
13–17	21	8.71	8.74	0.99	+0.03	+0
18–21	28	5.76	5.10	<0.01	(–0.66)	(–11)
28	76	8.06	7.20	0.10	(–0.86)	(–11)
29–32	147	6.06	5.04	<0.01	(–1.02)	(–17)

* Winter (December–February), Spring (March–May), Summer (June–August), Fall (September–November).
** Areas 1–8 (West Florida), 9–12 (Florida Panhandle, Alabama, Mississippi), 13–17 (Louisiana), 18–21 (Texas), 28 (Cape Canaveral), 30–31 (East Florida and Georgia), and 34–35 (North Carolina).

gia TED-equipped nets were 6.42 lb/h (TED with funnel) and 5.84 lb/h (TED without funnel). Paired standard nets caught 6.66 lb/h and 6.77 lb/h, respectively, exhibiting statistically-significant gains of 0.24 and 0.93 lb/h. Comparison of standard and Super Shooter TED-equipped nets showed a mean shrimp CPUE of 11.41 lb/h and 11.25 lb/h, respectively, for a statistically-nonsignificant loss of 0.16 lb/h with the Super Shooter TED.

Seasons CPUEs varied among seasons, just as abundance of shrimp on the fishery grounds varied among seasons. Shrimp CPUEs from standard nets and nets equipped with Super Shooter TEDs were not significantly different (Table 3). However, differences in shrimp CPUE between standard nets and nets with Georgia TEDs were significant during winter, spring, and summer. These values ranged from a gain of 0.34 lb/h to a loss of 0.67 lb/h by Georgia TED-equipped nets with a funnel (Table 4) and a loss of 0.70–1.13 lb/h by Georgia TED-equipped nets without a funnel (Table 5). CPUE differences due to TEDs were so small that they were likely masked by natural variations in shrimp CPUE.

Areas In most areas of the study, shrimp catch rates for TED-equipped nets were comparable with those for standard nets (Tables 3–5). Statistically-significant reductions (1.2 and 0.5 lb/h) in shrimp CPUE occurred off west Florida in nets equipped with Super Shooter TEDs and Georgia TEDs with funnels, respectively. Off Louisiana, standard nets caught 0.3 lb/h more shrimp than the paired Georgia TED-equipped nets with funnels. Shrimp CPUE was higher by 0.7 and 1.0 lb/h for standard nets paired with Georgia TED-equipped nets without funnels offshore of Texas and the east coast (Florida and Georgia), respectively.

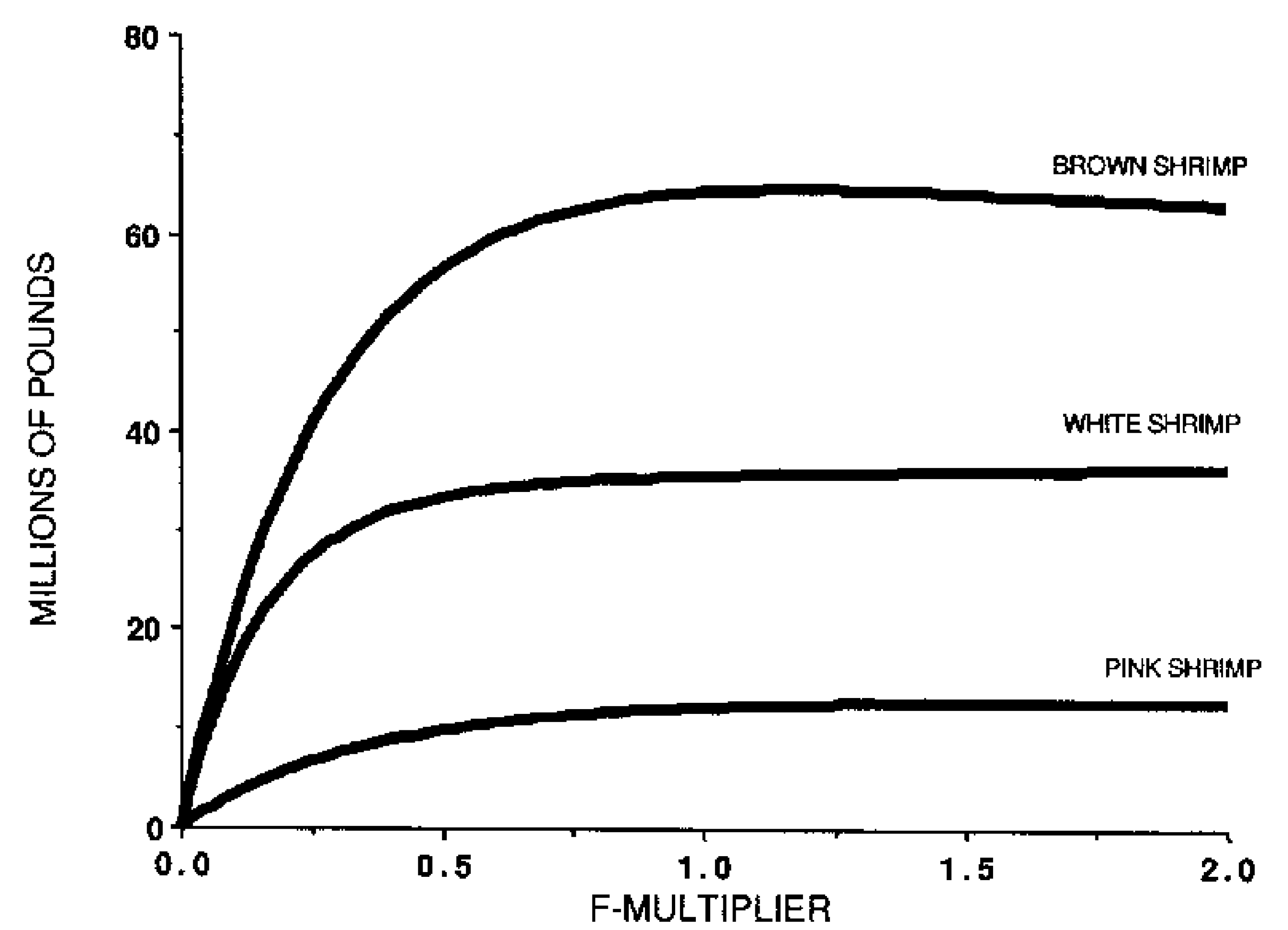

Figure 3
Yield models for brown *Penaeus aztecus*, white *P. setiferus*, and pink *P. duorarum* shrimp.

CPUE comparisons with commercial shrimp fleet in the Gulf of Mexico Average shrimp CPUE (heads-off lbs/24 h day/4 nets) by Statistical Area groupings and seasonal groupings for standard nets was compared with CPUE (heads-off lbs/24 h day/4 nets) for standard nets on other commercial vessels fishing in the same area and season in the Gulf of Mexico. Our initial assumption that our data were representative of commercial fishing conditions was supported by standard net CPUEs on commercial observer vessels that were not significantly different (paired *t*-test, $P>0.05$) from CPUEs on commercial vessels without observers. Mean differences ranged from a 6.2 lb/h gain by standard nets on TED observer vessels to a 4.9 lb/h gain by standard nets on other commercial vessels. In three of seven season/area combinations, shrimp CPUE from TED-observer vessels was higher than CPUEs of other commercial vessels. Since there were no significant differences in net size during our study, we assumed that this was the case for the rest of the commercial fleet. TED-observer vessels were apparently representative of other commercial vessels in the fleet fishing in similar areas during the same season. Similar analyses for the Atlantic fishery could not be made since catch information was not available on a trip-by-trip basis.

Biological yield models

Ricker-type yield models (Ricker 1975) developed for each of the three major shrimp species show the same basic curve shape (Fig. 3; Nance & Nichols 1988). The curves are asymptotic where yield estimates are plotted for current fishing mortality rates (F-multiplier = 1.0). Thus, with current fishing patterns and current fishing mortality rates, little increase or decrease in yield is predicted with the minor reductions in F that would be expected due to small losses of shrimp by TEDs.

Yield estimates were calculated in the model by varying the F-multiplier in increments of 0.02. Mean shrimp loss with TED-equipped vs. standard nets varied from 1 to 14% by TED type. A decrease of 5% in F would result in an undetectable change in annual yield in the brown or white shrimp fisheries and a 1% reduction in the annual yield of the pink shrimp fishery in the U.S. Gulf of Mexico.

Discussion

Our data were collected by NMFS observers during cooperative cruises with shrimp industry participants. Since this was a voluntary program, TED type, area, and season of sampling were controlled by industry participants. Data came from virtually any vessel whose owner or captain would allow NMFS observers aboard.

Not all federally approved TED types were tested. If a shrimper could not maintain TED efficiency during a trip, the trip was aborted by the shrimper or the TED was not used again. This resulted in nominal imbalances in the data by area, season, and TED type, including some data sets too small for analysis.

Mean shrimp catch rates in TED-equipped nets were lower than those in standard nets, varying from a loss of 1.4% with Super Shooter TEDs to a loss of 13.6% for Georgia TEDs without funnels. Nets equipped with Georgia TEDs without a funnel were used mainly during the first 6 months of this study. Higher losses of shrimp from these nets may be due to (1) initial inexperience by shrimpers using TEDs, (2) high losses of shrimp in rough-bottom areas, and (3) absence of a funnel in the TED. The lack of an accelerator funnel to assist shrimp movement past the escape opening of the TED could also account for some shrimp loss. The Georgia TED with an accelerator funnel exhibited a 3.6% reduction in shrimp CPUE compared with 13.6% by the Georgia TED without a funnel. Nets equipped with the Super Shooter TED exhibited the lowest reduction (1.4%) in shrimp CPUE when compared with the standard nets. This may have been due to (1) shrimpers having more experience with TEDs when this model was introduced during the second year of the study, and (2) more effective shrimp retention by the TED. The Super Shooter design also reduces clogging of TED bars by seagrasses and algae and may reduce shrimp loss. Although this TED exhibited the lowest reduction in shrimp CPUEs, it accounted for more problems during trawling than the other TEDs. These problems evidently did not affect shrimp catchability, since there was no significant difference between its catch rate and that of the paired standard net.

Areal differences in shrimp abundance may be confounded with CPUEs due to different types of TEDS and standard nets (flat nets, semiballoon nets, mongoose nets, etc.). Some TEDs work better on hard-bottom than on soft-bottom or with different types and abundances of bycatch. Georgia TEDs with funnels were the most common TED tested in Texas, Louisiana, and Florida. Super Shooter TEDs with funnels were used in North Carolina. The effectiveness of the TED type does influence the catch rates of shrimp.

Phares (1978), in describing the selectivity of shrimp nets, indicated that loss rates varied by area and season and affected an extensive size-range of lost shrimp. We have assumed (1) that shrimp escaping through either a TED-equipped net or a standard net will not die because of that episode, and (2) that escaping shrimp will grow and experience the same subsequent natural and fishing mortality as the rest of the stock. Thus, survival rates of shrimp escaping through the cod end of a standard net should be the same as those of shrimp escaping through the cod end of a TED net. Shrimp escaping through TED openings probably are not injured and are subject to subsequent recapture. Although decreases in CPUE may impact a given fisherman on any particular tow, these lost shrimp will still be available to fishermen for capture by succeeding tows.

Mathematical models indicated that a TED-induced decrease of 5% in F would result in an undetectable change in yield in the brown or white shrimp fisheries and a 1% reduction in the annual yield of the pink shrimp fishery in the U.S. Gulf of Mexico. Because of the asymptotic nature of the yield curves, only slight decreases in yield would be observed in some shrimp fisheries even if loss rates from TEDs were in the 10–20% range. With a 10% loss rate, we calculated a reduction from the pink shrimp fishery of 2% and no decreases in yield from either the white or brown shrimp fisheries. A 20% loss rate would result in a 4% reduction of the annual yield of pink shrimp and a 1–2% reduction for brown and white shrimp fisheries.

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